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Cork oak (*Quercus suber*) in the dynamism of a forest landscape shaped by fire on Monte Pisano (Tuscany N-W, Italy)

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Abstract

The plant landscape of Monte Pisano is characterized by a predominant forest component, with *Pinus pinaster* and *Castanea sativa*, of clear anthropic imprint. Another important component is constituted by dynamically advanced scrubs and woods of evergreen sclerophylls of natural origin, although often differently altered by the anthropic action and/or by fires, and dominated by *Quercus ilex*. *Quercus suber* is often found within holm oak woods, and – with lower frequency – inside the pine forests. Cork oak, in some cases, becomes dominant going to constitute the northernmost cork forests in Tuscany. The frequency of fires in Monte Pisano in the last decades seems to have led to an increase in *Q. suber* surface due to its known resilience to wildfires. The aim of this research is: a) to define the distribution of *Q. suber* in the area also in relation to repeated fire events in the past; b) to provide an updated characterization of these stands using a phytosociological approach; c) to identify stands and groups of trees that can be used as "seed forests" for post-fire forest restoration purpose, in relation to their marginal population characteristic. The study suggests a relationship between the spread of cork oak and the historical pattern of fires. This wide spread should be protected by forms of forest management unfortunately absent in this territory.

Keywords

Forest fire, phytosociology, post-fire regeneration, *Quercus suber*, *Quercion ilicis*

Introduction

The cork oak (*Quercus suber* L.) is a Mediterranean-Atlantic species with a large distribution in the Iberian Peninsula and in the north-western area of Morocco. From here it radiates along the coasts of the north-western Mediterranean up to the western and southern coasts of the Italian peninsula, including Corsica, Sardinia, and Sicily, while along the north-African coasts, it reaches Tunisia at the east (Barberis and Mariotti 1979; Blasi et al. 1997; Caudullo et al. 2017; Pignatti et al. 2017; Badalamenti et al. 2020). In Tuscany, it is widely distributed along the sub-coastal belt, with wide penetrations in the inland areas, from sea level to the hilly-mountain belts, where the climatic conditions allow it (Arrigoni et al.1999; Wikiplantbase #Toscana 2013) (Fig 1).

Even with this relatively large distribution, significant forests of *Q. suber* – i.e. continuous wooded areas not less than 0.5 ha – can be found, in Tuscany, only in some areas. From south to north, in the hilly areas and rarely in the plain, between the Ombrone River and the Metalliferous Hills (Selvi and Viciani 1999; Arrigoni et al. 1998; Selvi and Valleri 2012; Angiolini et al. 2021), in the Island of Elba (Foggi et al. 2006), and on Monte Pisano (Bertacchi et al. 2004). For all other reports on the Tuscan territory, these are almost always stations of a few individuals or isolated trees.

In this context, two different types of forest are identified. The open formations, where the cork appears between the dominant tree species, if not exclusive, and the closed formations, where it is co-dominant with or dominated by the holm oak. In any case, the communities where *Q. suber* is present in a significant way have been

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ascribed to several associations and sub-associations of *Fraxino orni-Quercion ilicis* (Arrigoni et al. 1998; Selvi and Viciani 1999; Bertacchi et al. 2004; Foggi et al. 2006; Selvi and Valleri 2012).

Within this syntassonomic classification, the cork oak woods are mainly interpreted as durable phases due to the periodic passage of fires (Selvi and Viciani 1999) or in any case as a more or less temporary replacement of the holm oak wood due to fire (Arrigoni 1998).

However, it should be remembered that the presence and expansion of the *Q. suber* woods is also favored by the anthropic activity linked to the extraction of cork (Arrigoni et al. 1998).

Thanks to its great resistance to fire and aerial vegetative regrowth, *Q. suber*, as known from the Iberian peninsula and other areas of the Mediterranean, can often give rise to a "pyroclimax" community (Mètro 1975), i.e. a secondary succession in equilibrium with a regime of repeated fires (Pausas 1997; Silva and Catry 2006; Schaffhauser et al. 2012).

The territory examined in this work is historically affected by forest fires. These, exclusively of anthropic origin, have often been repeated in the same areas and with the same intensity, at a short distance of years (AIB 2022). This has resulted in a constantly changing plant landscape, giving rise to a mosaic of regressive dynamic stages and secondary succession.

From the Vegetation Map of Monte Pisano (Bertacchi et al. 2004), the areas recurrently affected by fire since the last 50 years were covered by pine forests of *Pinus pinaster* Aiton subsp. *pinaster*, by evergreen sclerophyllous scrubs with *Q. ilex* and by post-fire shrub vegetation. In this context, the cork oak has revealed a remarkable resilience by persisting in the areas that were repeatedly burned (Bertacchi and Borgia 2019), and in some cases, even expanding over time (Bertacchi 2022).

The aims of this research were: a) to define the current distribution of *Q. suber* in the Monte Pisano; b) update the map of cork oak areas; c) characterize the vegetation of the *Q. suber* communities by mean of the phytosociological approach; d) identify a possible correlation between the current extent of the species and the diachronic trend of the fires in the last fifty years on the mountain. In addition, we wish identify the populations and group of trees of *Q. suber* that can be used as locally native "seed forests" for post-fire forest restoration.

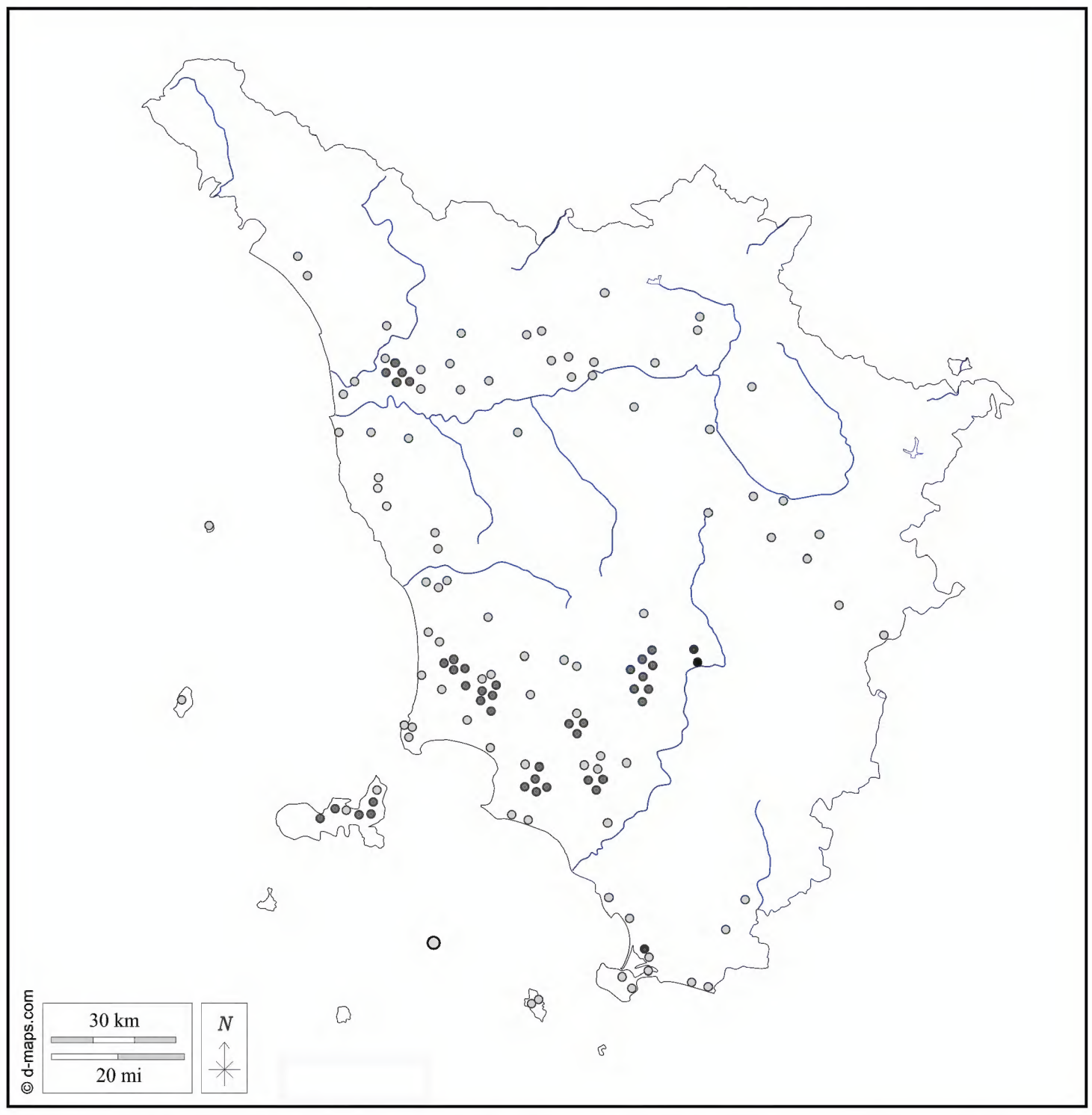

Figure 1. Distribution of *Quercus suber* L. in Tuscany (light grey circle: single occurrences /few individuals; dark gray circle: woods > 0.5 ha).

Methods

Study area

The investigation was carried out in the western and south-western slopes of Monte Pisano, falling entirely within the administrative sector of the Province of Pisa (north-western Tuscany) where the cork oak is unevenly distributed (Fig. 2). As regards the climate, the entire Monte Pisano falls within a temperate-humid climate with summer aridity, of the Mediterranean type, with an average temperature of the coldest month between -3°C and 18°C, and that of the hottest month higher than 22°C, and rainfall ranging from 900 mm to 1250 mm per year (Rapetti and Vittorini 1994). However, the investigated area falls within the type defined as climate B1, with higher average thermal values. From what can be deduced from the bioclimatic classification of Pesaresi et al. (2017), the study area falls within the pluvi-seasonal oceanic Mediterranean macro-bioclimate.

The extremely diversified geology of the Monte Pisano, in the investigated sector, can be attributed to two basic types. One characterized by rocks of a carbonate nature, only in some areas in the foothills of the mountain, and the other, predominantly, characterized by a matrix of quartzite rocks and conglomerates of sub-acid nature (Regione Toscana, Geoscopio, DB geologico).

The vegetation landscape of the Monte Pisano is mainly characterized by forests of maritime pine and coppice chestnut woods, both types with a clear anthropic character and in a state of abandonment. Another relevant component consists of garrigues, scrubs, and woods at different dynamic stage of evergreen sclerophyllous trees dominated by holm oaks, often with other broad-leaved trees such as cork oak, *Fraxinus ornus* L. subsp. *ornus* and, to a lesser extent, *Quercus pubescens* Willd. subsp. *pubescens* (Bertacchi et al. 2004). A large part of this second plant landscape, with the younger pine forests, is the result of a secondary succession determined by fires (Bertacchi and Borgia, 2019). The relief is in fact historically characterized, at least in the last 50 years and above all on the slopes of the Pisan side, by the recurrence of fires of anthropic origin (D.R.E.Am. Italia 2016; AIB 2022) (Fig. 3). In these slopes, *Q. suber* can be found mainly with scattered individuals or in small tree groups in post-fire scrubs, in evergreen sclerophyll woods, at the edges of olive groves, and mainly in open sites.

Despite this fragmentation, more significant stands are found in some areas of the slope. These plant communities form woods with two different physiognomies: closed forest, spared by the fire in the last 50 years, of sclerophyllous coppices with *Quercus ilex*, *Q. suber* and co-dominant deciduous broad-leaved trees (*Fraxino orni-Quercetum ilicis* Horvatic (1956) 1958 subass. *quercetosum suberis* Selvi et Viciani 1999), and cork oak woods of *Q. suber* (*Quercion ilicis* Br. Bl. (1931) 1936 em. Rivas-Martinez 1975); open scrubs formations with *Q. suber* (*Erico arboreae-Arbutetum unedonis* Allier et Lacoste 1980 subass. *quercetosum suberis* Selvi et Viciani 1999, which are found on surfaces hit by fire at least once in the considered period (Bertacchi et al. 2004; Bertacchi and Borgia 2019).

Data collection and processing

The presence and distribution of *Q. suber* in the investigated territory were carried out through fields surveys (2020-2022), and on the basis of the photo-interpretation and comparison of historical aero-photographic shoots, starting from the current state and backward in time

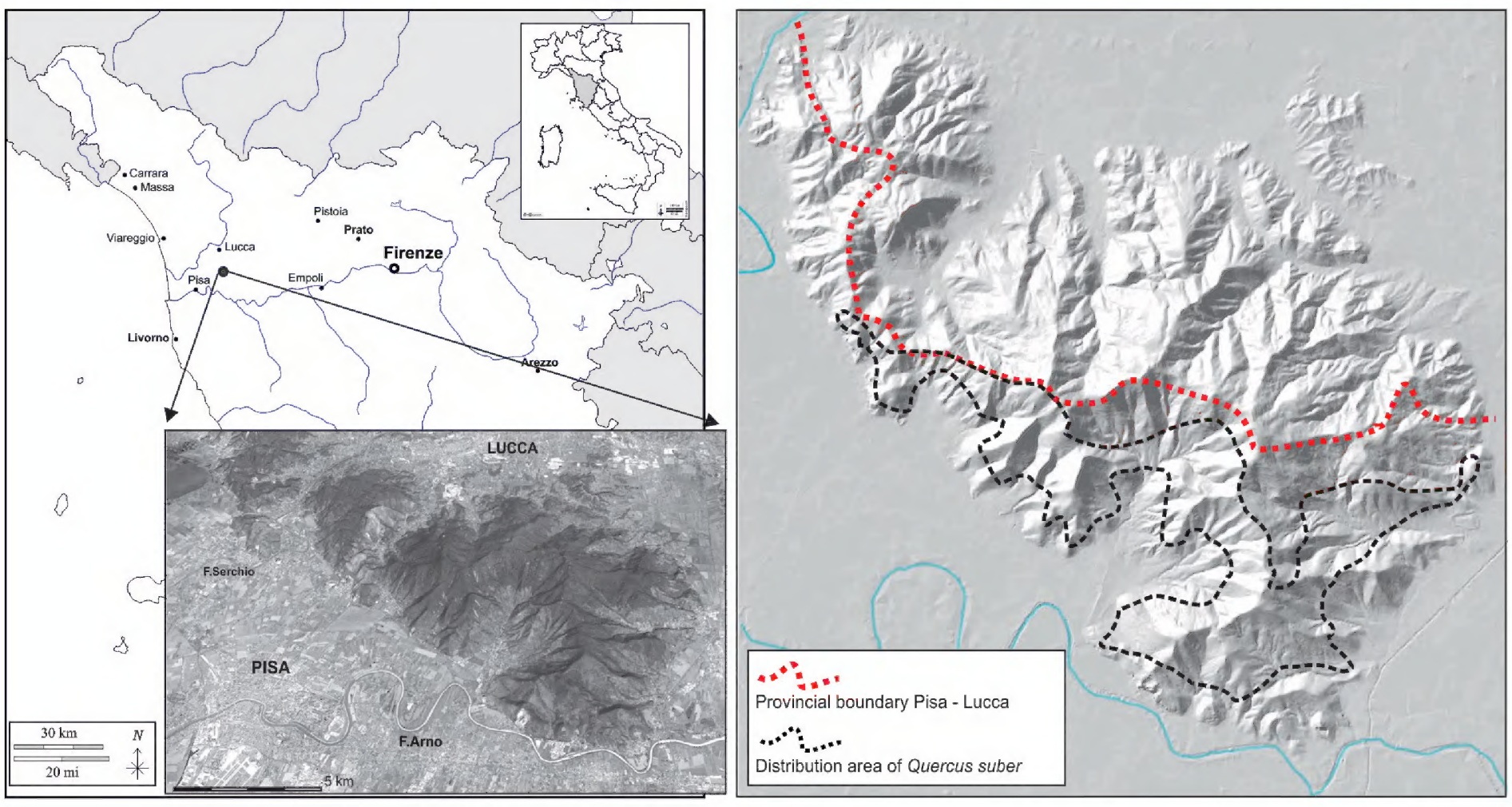

Figure 2. Location of the study area (DTM Base, Regione Toscana, Geoscopio).

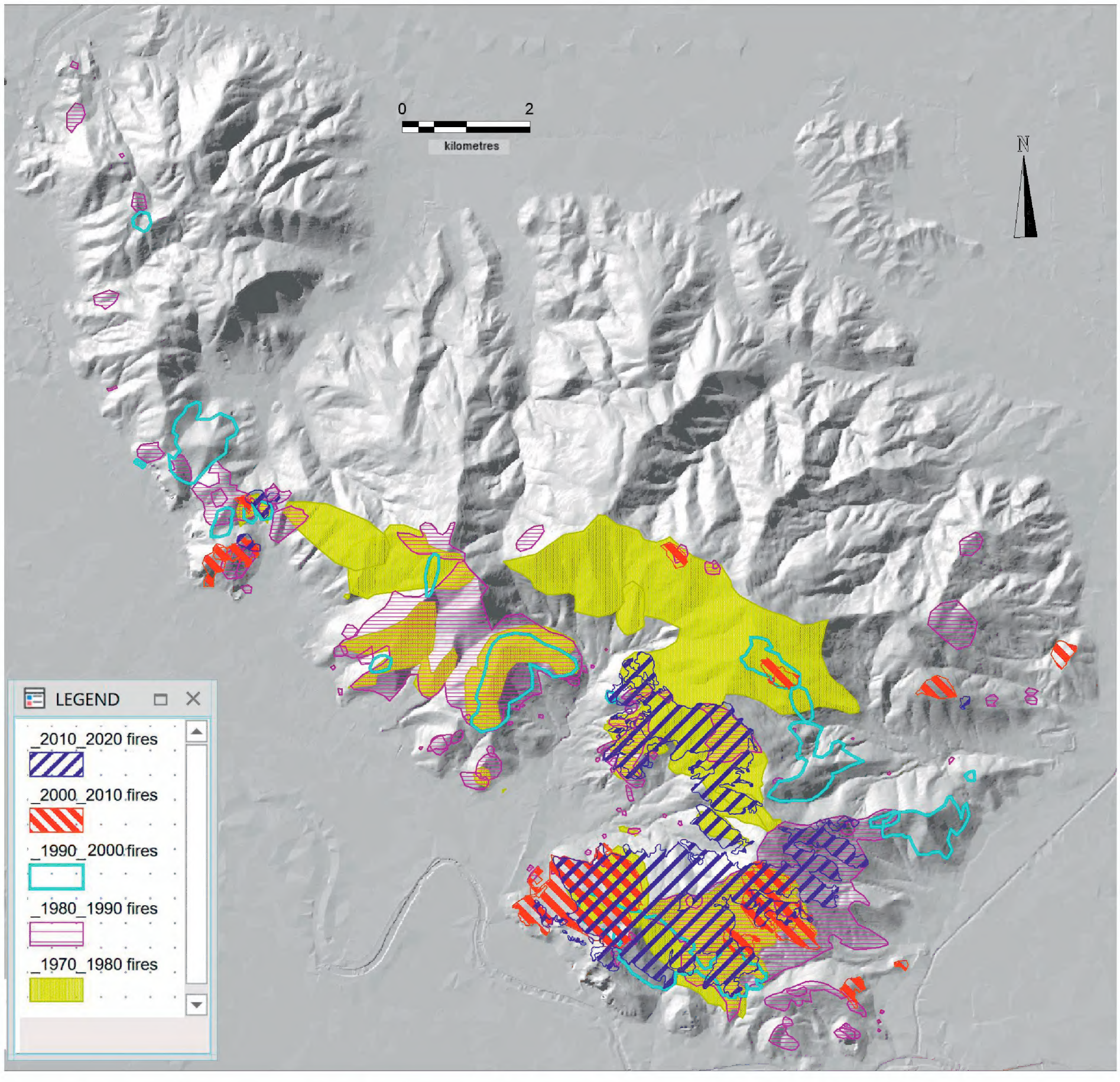

Figure 3. Areas of the Monte Pisano hit by wildfires on the Pisan side from 1970 to present (D.R.E.Am. Italia 2016 and AIB data, 2022; DTM Base, Regione Toscana, Geoscopio).

(Regione Toscana Geoscopio, Aerofoto 2019, 1965, 1954 flights; RAF flight, 1943). We also consulted the toponymy on the Leopoldine Land Registry of the second half of the 1800s (CASTORE, Regione Toscana Geoscopio). This analysis allowed us to draw a diachronic picture of the spatial dynamics of the species. Next, a phytosociological survey was carried out in the sites where there was a cork cover of at least 15%, by means of the Braun-Blanquet method (1983), for a total of 33 relevés.

Two tools of multivariate analysis of the vegetation data were carried out using the PAST 3.14 software (Hammer et al. 2001): the Cluster analysis by Ward's method and the PCA analysis on the variance-covariance matrix. This in order to highlight the phytocenotic relationships between the surveyed sites. The distribution of the *Q. suber* stands was subsequently mapped on a 100 m-side geographic grid with GIS MapInfo® and those exceeding 0.5 ha of surface have been drown on the map. The nomenclature of plant species follows Bartolucci et al. (2018) and subsequent updates from Portale della Flora d'Italia (2022). Syntaxa names comply with the International Code of Phytosociological Nomenclature (ICPN) (Theurillat et al. 2021).

Results

Past

On the Leopoldine cadastral cartography (end of the 19th century) of the investigated area, there are six toponyms referable to *Q. suber* ("La sughera", "Il sugherone", etc.),

five of which border the village of Asciano and one is immediately north to the village of Calci. From the analysis of the historical photos (1943-1954-1965) of the forest areas concerned, in those of 1943 and 1954 only the presence of forest cover could be ascertained, while in those of 1965, it was partly interpretable the type of forest cover. Consequently, in the two earliest aerial photographic series, it was impossible to identify individuals or cork oak populations with certainty, even by searching in the areas where the ancient toponyms could be superimposed. It was only possible to define that the most widespread vegetation type in the investigated area was scrub or, in extremely small areas, sparse woodland. Some areas were already hit by fire and devoid of tree vegetation. The aerial photos of 1965 showed a dynamic transition of the sparse forest into a closed forest and a partial transformation of the scrub into pine forests, following extensive reforestation interventions in the 1960s. In the aerial photos of 1965, some plant communities referable to cork oak woods could be identified.

Basically, the former distribution of the cork is only partially inferable. The toponyms indicate its presence in some areas in the north of the investigated area, where individuals of about 100 years old are found at present. These observations seem to be consistent with what reported by Bertacchi et al. (2004), where the cork oak communities are reported only for the areas mentioned here. These, however, seem in 2004 still limited to the northern sector of the area investigated.

Present

The field surveys allowed us to provide a distribution map of the cork oak on the Monte Pisano. This shows a wide distribution in the western quadrant, from the foot of the mountain up to a maximum elevation of about 450 m a.s.l. (Fig. 4A). The density was particularly high in the same woodland sites surveyed in the historical aerophotos of 1965 and in the areas with a short return time of the fire (cf. Fig. 3 and Fig. 4A).

The field surveys cross-referenced with the photo-interpretation of the recent aerial photos (2019) allowed to map the cork oak stands of at least 0.5 ha (Fig. 4C).

From the comparison with the 2004 vegetation map (Bertacchi et al. 2004), in the sector to the north of the village of Calci, there was a substantial overlapping with the cork oak forests existing today. By contrast, in the entire area south of Calci, below the Monte Verruca, the cork oak forest was not reported in the 2004 map, but was shown for the first time in 2018 (Bertacchi and Borgia 2019). This area, by the way, is the one of those who saw the greatest recurrence of fires since 1970.

In all the stands with *Q. suber* cover not less than 15%, species composition and abundance were detected.

The cluster analysis (Ward's method, Cophen. Corr. = 0.6) detected three main groups of vegetation relevés. (Fig. 5a). Group A included the stands with significant cover of *Q. suber*, the constant presence of *Q. ilex* and *F. ornus*, and an understorey characterized by *Smilax aspera*, *Rubia peregrina*, *Ruscus aculeatus*, and *Hedera helix* (Table 1). Relevés of group B, on the other hand, still showed a high cover of *Q. suber*, absence or low frequence /abundance of *Q. ilex* and *F. ornus* but a constant and important presence of *Erica arborea*, *Arbutus unedo* and, above all, *Cytisus villosus*; these species had a poor cover in group A, when present (Table 2). Group C showed an even high cover of *E. arborea* and *A. unedo* and the frequent presence of *Lavandula stoechas*, which was instead absent in the other two groups. *Phillyrea angustifolia*, had a high frequency and cover, only in group B. *Phillyrea latifolia* is poorly represented in all three groups (Table 3).

The Ordination by PCA highlighted the three groups of relevés and the species that constitute the main elements of differentiation (Fig. 5b).

From a phytosociological point of view, group A can be referred to the *Fraxino orni-Quercetum ilicis* Horvatic (1956) 1958 subass. *quercetosum suberis* Selvi and Viciani 1999 (Table1). According to the more recent work by Biondi et al. (2013), *Fraxino orni-Quercetum ilicis* is not an association suitable for Italy, and must be replaced by *Cyclamen hederifolii-Quercetum ilicis* Biondi, Casavecchia & Gigante ex Biondi, Casavecchia & Gigante in Biondi, Allegrezza, Casavecchia, Galdenzi, Gigante & Pesaresi 2013. Some relevés (no. 4, 5, 6, 7, 21, 22), however, were carried out in the only wooded areas not hit by fire during the last 70 years. Group B is a rather heterogeneous group and can be referred to two alliances: *Fraxino orni-Quercion ilicis* Biondi, Casavecchia and Gigante in Biondi et al. 2013 and *Erico arboreae-Quercion ilicis* Brullo, Di Martino and Marcenò 1977 (Table 2). This combination seems essentially linked to the dynamic stage of the phytocoenoses or to the level of degradation derived almost exclusively from the passage of fire.

Group C can be referred to *Erico arboreae-Arbutetum unedonis* Allier et Lacoste 1980 subass. *quercetosum suberis* Selvi et Viciani 1999 (Table 3).

Discussion and conclusion

Based on our findings about the forest landscape of the Monte Pisano, the cork oak is distributed, with different density, only on the western and south-western sides of the mountain. Here, the environmental and soil conditions that are most suited to the ecology of the species occur. In fact, the microclimate of the area, given the close proximity to the sea, has Mediterranean characteristics with oceanic influences, in which the cork oak finds its climatic optimum. Furthermore, the prevailing lithology of the slope considered is given by acid and sub-acid quartzite rocks.

However, the distribution is not uniform and appears to be linked to different land uses or destructive events such as fires. In the first case, the mountain range that the cork oak would naturally occupy is historically covered to

Table 1. Sclerophyllous coppices with deciduous broadleaves with co-dominant *Quercus suber* L. and *Quercus ilex* L. (*Fraxino orni-Quercetum ilicis* Horvatic (1956) 1958 subass. *quercetosum suberis* Selvi et Viciani 1999) (Group A).

Relevé number	4	21	22	7	5	6	17	18	15	16	25	8
Altitude	30	180	190	50	50	50	180	240	100	120	300	120
Slope aspect	SE	W	W	SE	SE	SE	SW	W	NW	W	NW	SE
Geological substrate	QF	QF	QF	QF	QF	QF	QF	QF	CO	CO	QF	QF
Surface (m^2)	150	150	150	100	150	100	150	150	100	100	150	100
Ground cover (%)	100	100	100	100	100	80	80	100	100	100	100	80
Charact. and diff. species of the ass. *Fraxino orni-Quercetum ilicis*												
Quercus ilex L.	2	2	1	2	1	1	.	+	3	2	2	1
Fraxinus ornus L. subsp. *ornus*	1	1	1	1	1	2	1	1	1	1	.	+
Viburnum tinus L. subsp. *tinus*	.	+	+	.	.	.	.	.	.	.	.	.
Erica arborea L.	.	+	.	+	1	.	r	r	+	1	+	.
Lonicera implexa Aiton subsp. *implexa*	.	.	+	+	.	.	.	.	.	.	+	.
Dioscorea communis (L.) Caddick & Wilkin	.	.	.	.	.	+	.	.	+	+	+	+
Carex distachya Desf.	r	.	r	+	.	.	.	.	.	.	.	.
Asplenium onopteris L.	.	+	+	.	.	.	.	.	+	.	.	.
Charact. and diff. species of the subass.												
Quercus suber L.	4	3	4	1	3	1	2	2	2	2	3	1
***Quercetea, Quercetalia, Quercion ilicis* Br.Bl. 1947**												
Arbutus unedo L.	.	+	.	.	.	1	.	+	+	+	1	+
Phillyrea angustifolia L.	.	r	.	+	.	.	.	.	.	.	+	1
Phillyrea latifolia L.	.	.	r	.	.	.	.	.	.	.	.	.
Smilax aspera L.	2	2	1	2	3	2	.	.	.	.	1	.
Pistacia lentiscus L.	.	+	.	.	.	.	.	.	.	.	.	.
Ruscus aculeatus L.	+	+	+	1	.	+	+	.	1	+	.	.
Asparagus acutifolius L.	.	+	+	+	r	+	.	.	.	.	.	.
Rubia peregrina L.	1	+	+	+	+	+	+	+	+	+	+	.
Cyclamen hederifolium Aiton subsp. *hederifolium*	.	+	+	+	.	+	.	.	.	.	.	.
Quercus pubescens Willd. subsp. *pubescens*	.	.	.	.	r	1	+	+	.	.	r	1
Osyris alba L.	.	.	.	.	.	.	+	.	.	.	.	+
Pinus pinaster Aiton subsp. *pinaster*	.	1	1	.	+	.	2	2	+	.	1	.
Arisarum vulgare O.Targ.Tozz. subsp. *vulgare*	r	+	.	.	.	.	.	.	.	.	+	.
Laurus nobilis L.	.	.	.	.	.	.	.	.	.	+	.	.
Others												
Myrtus communis L.	.	+	.	.	.	.	r	.	.	.	+	.
Hedera helix L. subsp. *helix*	1	+	+	+	1	+	+	+	+	+	.	.
Erigeron canadensis L.	.	.	.	.	r	1	+	+	.	.	r	1
Emerus major Mill. subsp. *major*	+	+	.	.	.	+	+	.	.	.	.	.
Cytisus villosus Pourr.	+	+	+	.	.	.	.	.	.	.	.	.
Rubus sp.	.	.	.	.	.	.	r	r	.	.	.	.
Genista monspessulana (L.) L.A.S.Johnson	.	.	r	.	.	.	.	.	.	.	.	.
Genista pilosa L.	+	.	.	.	.	.	.	.	.	.	.	.
Brachypodium sylvaticum (Hud.) Beauv.	+	+	+	.	.	.	+	+	.	.	.	.
Brachypodium retusum (Pers.) P. Beauv	.	.	.	.	.	.	.	.	.	.	.	+
Cistus salviifolius L.	.	.	.	.	.	.	+	.	.	.	.	+
Macrobriza maxima (L.) Tzvelev	.	.	.	.	.	.	+	.	.	.	.	.
Lotus hirsutus L.	.	.	.	.	+	.	.	.	.	.	.	.
Viola reichembachiana Jord. ex Boureau	.	+	.	.	.	.	.	.	.	.	+	.
Serapias vomeracea (Burm. f.) Briq.	.	+	.	.	.	.	.	.	.	.	.	.
Cornus sanguinea L. subsp. *sanguinea*	r	.	.	.	.	.	.	r	.	.	.	.
Crataegus monogyna Jacq	.	.	.	.	.	+	.	.	.	.	.	.
Pteridium aquilinum (L.) Kuhn subsp. *aquilinum*	+	.	.	.	.	.	r	.	.	.	.	.
Spartium junceum L.	.	.	.	.	.	+	.	.	.	.	.	.
Pulicaria odora (L.) Rchb	.	.	.	+	.	.	.	.	.	.	.	.

a large extent by terraced olive groves. Here cork oak can only be found as isolated individuals or in small rows at the edge of the terraces. The numerous and extensive areas reforested with pine trees from the eighteenth century until the second half of the last century, in surfaces unsuitable for the cultivation of the olive tree, have further reduced the range of *Q. suber*. This fact has reduced the possibility of spreading the cork oak, as noted in other contexts of Tuscany (Selvi et al. 2016). In this context, cork oak phytocoenoses of a certain size can only be found on the margins of these agro-forestry surfaces where, both from the toponymy and the analysis of historical aerial photos, their former and long-lasting existence can be confirmed. These phytocoenoses also represent those sta-

Table 2. Open scrublands of *Quercus suber* L. with an understorey of *Arbutus unedo* L., *Erica arborea* L., *Phillyrea angustifolia* L. and *Cytisus villosus* Pourr. (*Fraxino orni-Quercion ilicis* Biondi, Casavecchia et Gigante in Biondi et al. 2013; *Erico arboreae-Quercion ilicis* Brullo, Di Martino & Marcenò 1977 (Group B) .

Relevé number	29	9	10	23	32	24	35	36	30	31	33	34
Altitude	330	150	150	250	150	250	250	250	100	150	150	170
Slope aspect	S	W	W	NW	W	W	W	SW	W	W	SW	SW
Geological substrate	QF	QF	CO	QF	QF	QF	QF	QF	QF	QF	QF	QF
Surface (m^2)	200	100	100	150	100	200	100	100	100	100	100	100
Ground cover (%)	80	100	80	80	80	80	80	80	80	50	80	80
***Fraxino orni-Quercion ilicis* Biondi, Casavecchia et Gigante in Biondi et al. 2013**												
Quercus ilex L.	1	.	.	.	.	.	+	.	.	.	.	.
Fraxinus ornus L. subsp. *ornus*	.	.	+	1	.	+	+	.	.	.	+	.
Viburnum tinus L. subsp. *tinus*	.	.	.	.	r	.	.	.	.	.	.	.
Lonicera implexa Aiton subsp. *implexa*	+	.	.	.	.	.	r	r	.	.	+	+
***Erico arboreae-Quercion ilicis* Brullo, Di Martino & Marcenò 1977**												
Quercus suber L.	5	4	3	3	4	3	2	2	1	1	3	3
Erica arborea L.	1	.	+	.	+	+	1	1	1	2	+	+
Arbutus unedo L.	+	1	1	1	+	2	2	2	.	+	+	.
Cytisus villosus Pourr.	+	.	+	1	2	3	2	2	2	2	1	1
Cistus monspeliensis L.	1	.	.	.	.	.	.	.	.	+	.	.
Cistus salviifolius L.	.	.	.	.	.	+	+	r	1	1	+	.
Asplenium onopteris L.	.	.	.	+	.	.	.	.	.	.	.	.
***Quercetea, Quercetalia* Br.Bl. 1947**												
Phillyrea angustifolia L.	+	.	1	r	+	.	2	+	1	+	+	1
Smilax aspera L.	+	+	+	+	+	.	1	1	1	1	2	2
Ruscus aculeatus L.	.	.	.	.	.	+	.	.	.	.	.	.
Asparagus acutifolius L.	+	.	.	.	.	.	+	.	.	.	+	.
Rubia peregrina L.	+	+	.	+	.	+	+	+	+	+	1	1
Cyclamen repandum Sm. subsp. *repandum*	.	.	.	.	.	.	r	.	.	.	.	.
Pinus pinaster Aiton subsp. *pinaster*	+	.	.	+	.	.	+	.	.	.	.	r
Quercus pubescens Willd. subsp. *pubescens*	.	+	.	.	.	.	+	.	.	+	.	.
Osyris alba L.	+	.	.	.	.	+	.	.	.	.	.	.
Others												
Emerus major Mill. subsp. *major*	.	.	.	r	.	1	.	r	.	.	+	.
Cupressus sempervirens L.	+	.	.	.	.	.	.	.	.	.	.	.
Myrtus communis L.	+	.	.	1	.	+	+	+	+	+	.	1
Hedera helix L. subsp. *helix*	.	1	1	+	.	.	.	.	.	.	.	.
Rubus sp.	.	1	.	.	.	+	+	.	+	.	.	.
Rhamnus alaternus L. subsp. *alaternus*	.	.	.	.	.	.	+	.	.	.	.	.
Genista monspessulana (L.) L.A.S.Johnson	.	.	.	.	.	.	+	.	.	.	.	.
Genista pilosa L.	.	.	.	.	.	.	.	.	+	+	.	.
Genista germanica L.	.	.	.	+	.	+	.	.	.	.	.	.
Brachypodium sylvaticum (Hud.) Beauv.	+	.	.	+	.	.	.	.	.	.	+	.
Brachypodium retusum (Pers.) P. Beauv	.	.	+	.	.	.	.	.	.	.	.	.
Teucrium camaedrys L. subsp. *chamaedrys*	.	.	.	+	.	.	+	.	.	+	+	+
Macrobriza maxima (L.) Tzvelev	.	.	.	.	.	.	.	.	+	+	.	.
Aira elegans Willd. subsp. *elegans*	.	.	.	.	.	.	.	.	r	.	.	.
Crataegus monogyna Jacq	.	.	+	.	.	.	.	.	.	.	.	.
Pteridium aquilinum (l.) Kuhn	r	.	.	.	.	.	.	.	.	.	.	.
Pulicaria odora (L.) Rchb	.	+	+	.	.	.	.	.	.	+	.	.
Clematis flammula L.	r	.	.	.	.	.	.	.	.	.	.	.
Ornithopus compressus L.	.	.	.	.	.	.	.	.	+	+	.	.
Dittrichia viscosa (L.) Greuter subsp. *viscosa*	.	.	.	.	.	.	.	.	.	+	.	.
Erigeron canadensis L.	.	+	.	.	.	.	+	.	.	+	.	.

tions with more defined vegetational characteristics and with the most ancient individuals.

In the latter case, cork oak phytocoenoses with variable density are scattered throughout the southwestern slopes. Here, the maximum density of *Q. suber* is found in three areas where fires have been most frequent in the last 50 years (Fig. 6).

In these contexts, the phytocenotic characteristics of the cork oak stands seem to be diversified, both physiognomically and floristically, mostly by the time of recurrence of the fires. The type of vegetation pre-existing fire is, at least in the last 50 years, attributable to the forest of maritime pine. This, without excluding the presence on Monte Pisano of primordial and native presence of maritime pine (Targioni-Tozzetti 1768), can be attributed almost entirely to artificial plantations in historical times. In the foothills of the mountain, the pine replaced holm oak and ericaceous sclerophyllous scrubs and, at higher elevations, black hornbeam and other broad-leaved woods (Cosci and Giacobbe 1953). The current differ-

Table 3. Scrublands of *Quercus suber* L. with understorey of *Arbutus unedo* L. and *Erica arborea* L. (*Erico arboreae-Arbutetum unedonis* Allier et Lacoste 1980 subass. *quercetosum suberis* Selvi et Viciani 1999) (Group C).

Relevé number	19	26	28	20	13	27	11	3	37
Altitude	340	330	570	340	150	550	150	120	350
Slope aspect	W	SW	W	SW	W	W	W	S	S
Geological substrate	QF	QF	QF	QF	QF	QF	QF	QF	QF
Surface (m^2)	200	150	200	200	100	200	100	100	100
Ground cover (%)	50	80	50	60	100	80	100	100	80
Charact. and diff. species of the ass. *Erico-Arbutetum*									
Erica arborea L.	+	1	1	2	2	2	2	2	1
Arbutus unedo L.	3	2	2	1	2	3	3	2	3
Charact. and diff. species of the subass.									
Quercus suber L.	2	2	3	3	2	2	1	1	2
***Quercetea, Quercetalia, Quercion ilicis* Br.Bl. 1947**									
Quercus ilex L.	.	.	+	.	.	+	.	.	.
Fraxinus ornus L. subsp. *ornus*	1	+	.	+	.	+	.	.	.
Phillyrea angustifolia L.	.	+	.	.	.	.	.	+	+
Phillyrea latifolia L.	.	.	1	+	.	+	+	.	+
Smilax aspera L.	.	+	.	+	+	+	+	1	+
Rubia peregrina L.	.	.	.	.	+	+	.	.	r
Carex distachya Desf.	.	.	.	.	.	.	.	.	+
Pinus pinaster Aiton subsp. *pinaster*	.	1	+	+	.	+	.	2	1
Quercus pubescens Willd. subsp. *pubescens*	.	.	.	.	.	+	.	.	.
Others									
Myrtus communis L.	.	+	.	.	.	.	1	.	.
Rubus sp.	.	.	.	.	+	.	.	+	1
Cytisus villosus Pourr.	.	.	+	.	+	+	.	+	+
Rhamnus alaternus L. subsp. *alaternus*	.	.	.	.	.	.	+	.	.
Ulex europaeus L. subsp. *europaeus*	.	+	.	+	+	.	.	.	.
Genista pilosa L.	.	+	.	.	.	.	+	.	.
Brachypodium sylvaticum (Hud.) Beauv.	.	+	.	.	.	+	.	+	.
Brachypodium retusum (Pers.) P. Beauv	.	.	.	.	+	.	1	.	.
Teucrium scorodonia L.	.	+	.	.	.	.	.	.	.
Teucrium camaedrys L. subsp. *chamaedrys*	+	.	.	+	.	+	.	+	.
Cistus monspeliensis L.	.	+	.	+	.	.	.	.	.
Cistus salviifolius L.	+	.	.	+	+	.	.	+	r
Macrobriza maxima (L.) Tzvelev	.	+	.	+	.	.	.	+	.
Calluna vulgaris (L.) Hull	.	+	+	+	.	.	.	.	.
Lavandula stoechas L. subsp. *stoechas*	3	1	+	1	.	+	+	.	.
Lotus hirsutus L.	.	.	.	+	.	.	.	.	.
Crataegus monogyna Jacq	+	.	.	.	+	.	.	+	.
Daphne gnidium L.	r	.	.	.	.	.	.	.	.
Spartium junceum L.	.	.	.	.	+	.	.	.	.
Erigeron canadensis L.	.	.	.	.	.	+	.	.	.

ent phytocenotic characteristics would therefore seem to represent, in the majority of cases, different post-fire stages of a vegetation series attributable to the indifferent edaphic Tyrrhenian Italic series of holm oak (*Cyclamino repandi-Quercetum ilicis sigmetum*) or, in part, to the central subacidophilous Tyrrhenian series of the cork oak (*Cytiso villosi-Quercetum suberis sigmetum*) (Blasi 2010). In the investigated area, the dynamic trend of the areas hit by the fire seems to follow two paths. In the absence of new fires, a secondary succession that leads to mixed woods of holm oak and cork oak, while in the case of further fires, a series of secondary successions in equilibrium with a regime of repeated fires which maintains cork oak scrub. In this context, in microclimatic conditions consistent with the historical averages, a succession towards forest typologies with a prevalence of deciduous trees would likely occur, as observed in other Tuscan contexts (Spada 1993). Conversely, the occurrence of concomitant stress phenomena such as severe aridity and repetition of fires could lead to a degradation of the cork oak communities (Acacio et al. 2009). In our case study, the only two forest formations not affected by fire in the period considered seem to show stable characteristics of the evergreen sclerophyllous forest, albeit with frequent participation of deciduous trees such as *Q. pubescens* and *F. ornus* (Table 1: rels 4, 5, 6, 7, 8, 21, 22). All the other surveys highlighted, together with the constant presence and predominance of cork oak, aspects of scrub in different dynamic stages, in relation to the historical recurrence of the fires. The current extension of the species in the investigated area is therefore the result of environmental factors consistent with the ecology of the species and incidental factors (fire) favoring its diffusion.

If a detailed diachronic comparison between the past extension and the current one is not objectively possible, the overlap of its current distribution area and the

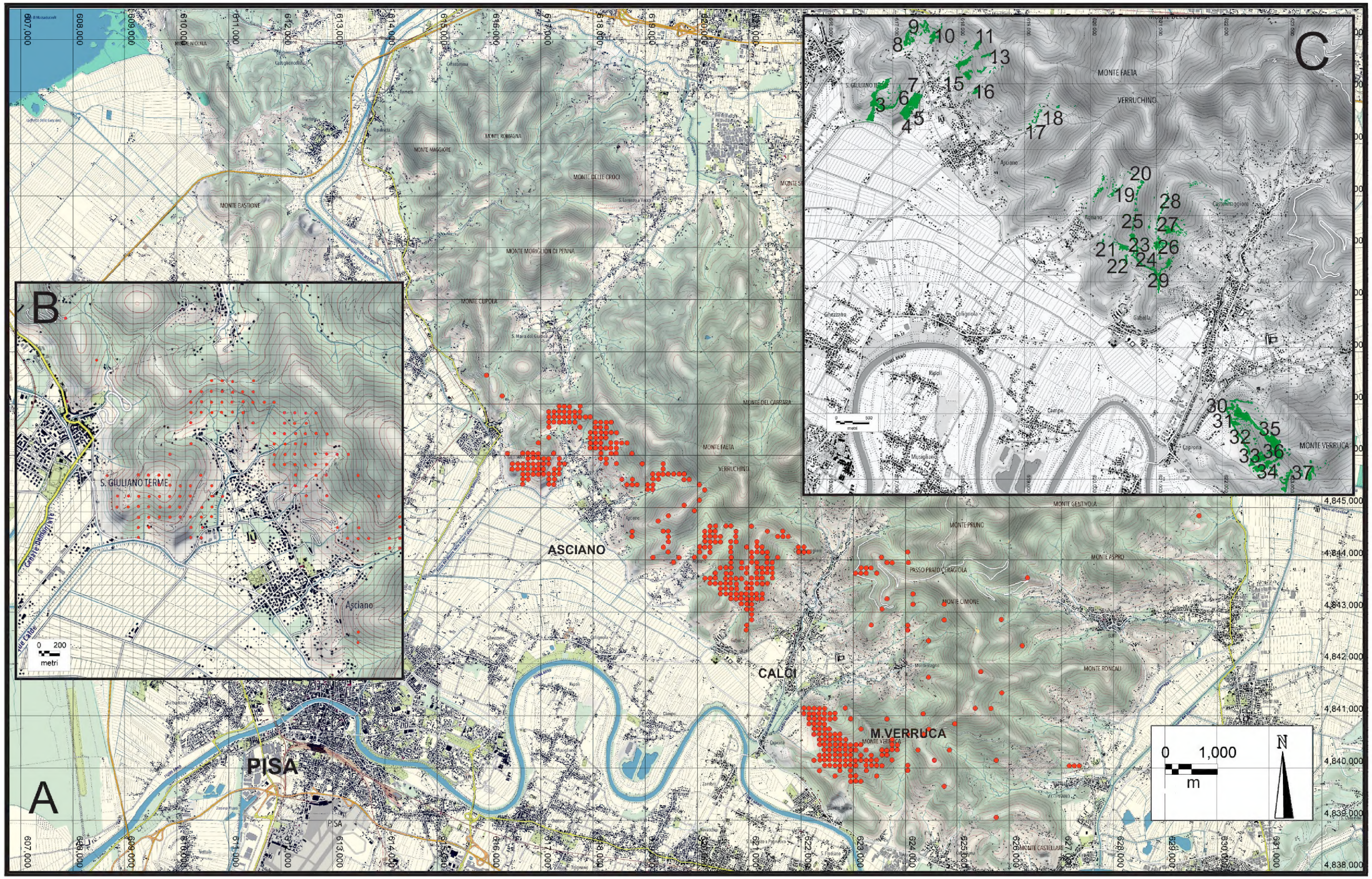

Figure 4. Distribution of *Q. suber* on the Monte Pisano: A) distribution over the entire area; B) detail on quadrants with sides of 100 m; C) *Q. suber* populations exceeding 5,000 sqm and positions of the surveys (Topographic Map:Regione Toscana, Geoscopio).

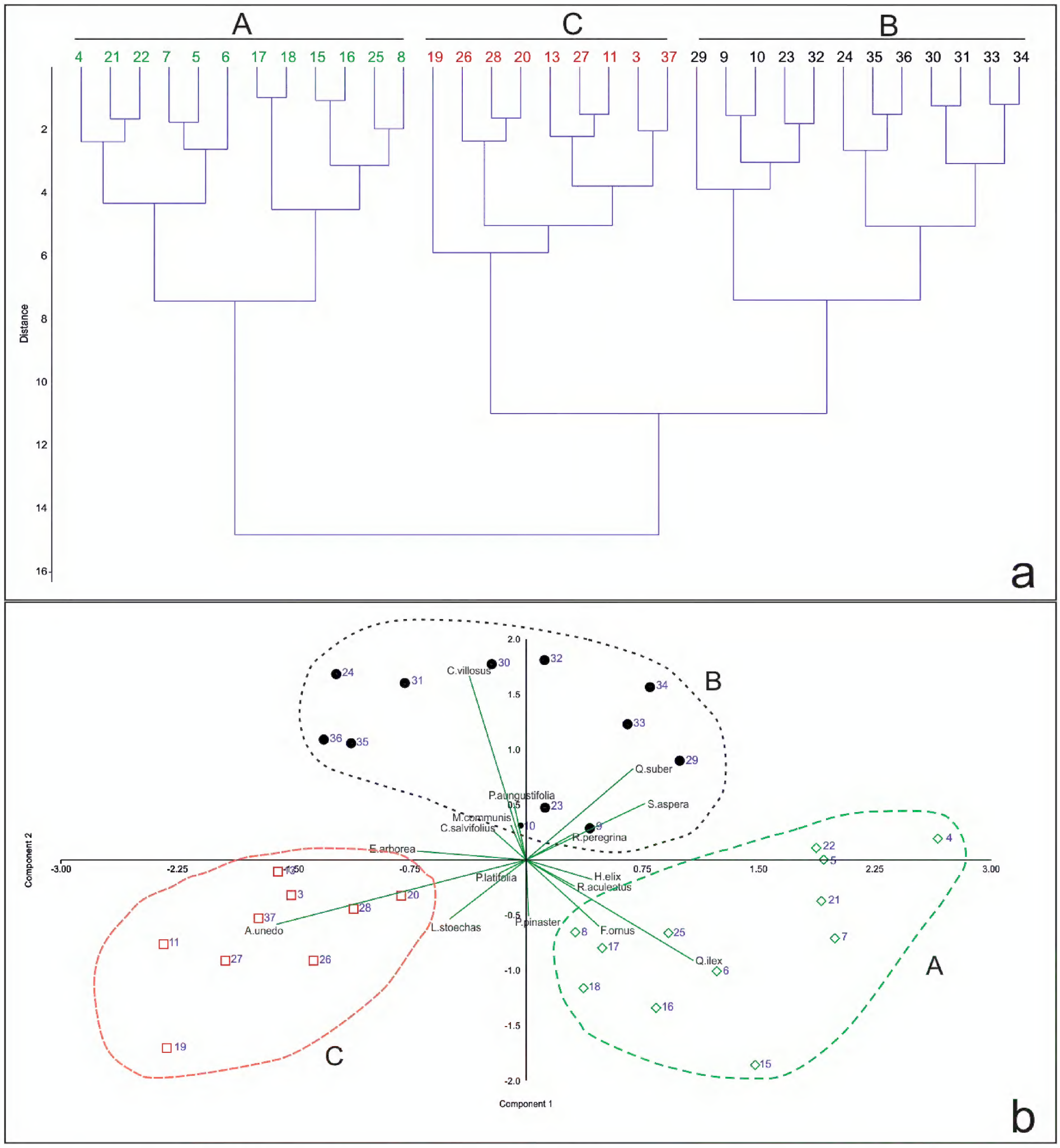

Figure 5. Dendrogram from cluster analysis (a) and scattergram from PCA (b) of vegetation relevés. (PC1 eingenvalue = 1.91232, % variance = 27.839; PC2 eingenvalue = 1.09639% variance 15.961).

area affected by fires in the last 50 years is nevertheless rather evident (Fig. 6). In any case, in the areas under Monte Verruca, which in the historical vegetation cartography were covered by post-fire scrub or pine forests (Bertacchi et al. 2004), today, after the last fires of 2008 and 2019, *Q. suber* is the most widespread tree species with detectable canopy.

The presence of the Habitat 9330 (EU directive habitats 92/43) in the Monte Pisano, is not clearly identifiable, although in some areas cork stands could be referred to the latter. The physiognomic and floristic characteristics of these cork oak communities have strong transitional characteristics caused by repeated anthropic fires, so as to consider these habitats as secondary habitats. In the stands for a long time no longer crossed by the fire, the forest tends to close, the herbaceous/ shrubby layer to decrease and to change the ratio of dominant tree species. Actually, all the more mature stages of cork forests seem to go in the direction of habitat 9340. In the perspective of forest restoration interventions on Monte Pisano, the native cork oak populations, partly unaffected by fire and partly survived to it, can be used as "forests for seed" of

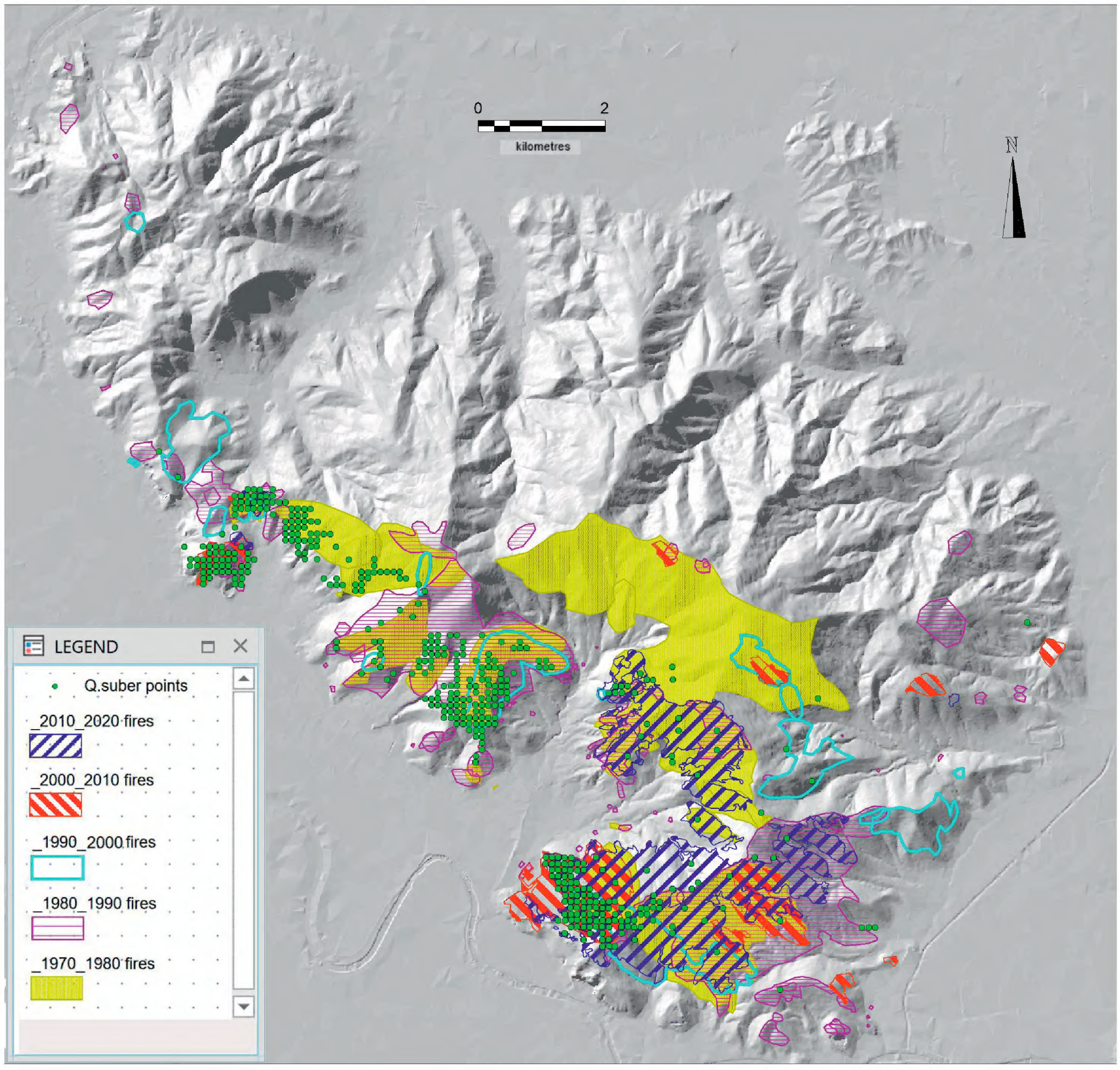

Figure 6. Superposition of the main stands of *Q. suber* with the diachronic map of the fires (fifty years).

locally native germplasm. In these stands, a management of the forest capable of keeping its structure open is to be suggested. Furthermore, the widespread presence of Fabaceae shrub species such as *Cytisus villosus* and *Genista* sp. in the more recently burned areas could be considered for reforestation interventions.

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Appendix I – Projected coordinates of the 33 relevés (Lat and Long; UTM Zone 32, Northern Emisphere; WGS 84, EPSG 32632)

Table 1 – Rel. 4: 4845519.44-617186.84; rel. 21: 4843555.93-620408.09; rel. 22: 4843524.26-620485.56; rel. 7: 4845728.69-617320.87; rel. 5: 4845567.23-617172.71; rel. 6: 4845605.12-617216.81; rel. 17: 4845538.09-619195.59; rel. 18: 4845439.69-619188.81; rel. 15: 4846325.87-618121.09; rel. 16: 4846293.07-618038.53; rel. 25: 4843714.28-620620.15; rel. 8: 4846717.21-617211.16.

Table 2 – Rel. 29: 4843151.01-621047.13; rel. 9: 4846848.99-617508.63; rel. 10: 4846711.57-617657.93; rel. 23: 4843358.00-620691.97; rel. 32: 4840178.89-622494.59; rel. 24: 4843305.41-620734.39; rel. 35: 4840225.26-622844.08; rel. 36: 4840211.12-622688.56; rel. 30: 4840987.59-622248.59; rel. 31: 4840826.98-622315.89; rel. 33: 4840176.06-622587.90; rel. 34: 4840281.24-622777.35.

Table 3 – rel. 19. 4844336.92-620327.77; rel. 26: 4843554.24-621047.69; rel. 28: 4844066.03-621082.18; rel. 20: 4844334.66-620369.06; rel. 13: 4846413.53-618390.29; rel. 27: 4844003.26-621061.82; rel. 11: 4846613.73-618119.96; rel. 3: 4845643.57-616979.29; rel. 37: 4840149.62-623359.98.